

## Telemedicine in Prehospital Acute Stroke Care

Frederik Geisler, MD;\* Alexander Kunz, MD;\* Benjamin Winter, MD; Michal Rozanski, MD; Carolin Waldschmidt, MD; Joachim E. Weber, MD; Matthias Wendt, MD; Katja Zieschang, MD; Martin Ebinger, MD; Heinrich J. Audebert, MD; on behalf of the Stroke Emergency Mobile (STEMO) Consortium<sup>†</sup>

**Background**—Mobile stroke units (MSUs), equipped with an integrated computed tomography scanner, can shorten time to thrombolytic treatment and may improve outcome in patients with acute ischemic stroke. Original (German) MSUs are staffed by neurologists trained as emergency physicians, but patient assessment and treatment decisions by a remote neurologist may offer an alternative to neurologists aboard MSU.

**Methods and Results**—Remote neurologists examined and assessed emergency patients treated aboard the MSU in Berlin, Germany. Audiovisual quality was rated by the remote neurologist from 1 (excellent) to 6 (insufficient), and duration of video examinations was assessed. We analyzed interrater reliability of diagnoses, scores on the National Institutes of Health Stroke Scale and treatment decisions (intravenous thrombolysis) between the MSU neurologist and the remote neurologist. We included 90 of 103 emergency assessments (13 patients were excluded because of either failed connection, technical problems, clinical worsening during teleconsultation, or missing data in documentation) in this study. The remote neurologist rated audiovisual quality with a median grade for audio quality of 3 (satisfactory) and for video quality of 2 (good). Mean time for completion of teleconsultations was about 19±5 minutes. The interrater reliabilities between the onboard and remote neurologist were high for diagnoses (Cohen's  $\kappa=0.86$ ), National Institutes of Health Stroke Scale sum scores (intraclass correlation coefficient, 0.87) and treatment decisions (16 treatment decisions agreed versus 2 disagreed; Cohen's  $\kappa=0.93$ ).

**Conclusions**—Remote assessment and treatment decisions of emergency patients are technically feasible with satisfactory audiovisual quality. Agreement on diagnoses, neurological examinations, and treatment decisions between onboard and remote neurologists was high. (*J Am Heart Assoc.* 2019;8:e011729. DOI: 10.1161/JAHA.118.011729.)

**Key Words:** emergency medical services • emergency medicine • ischemic stroke • telemedicine • thrombolysis

A reduction in symptom onset to start of thrombolysis time in patients with acute ischemic stroke is associated with better functional outcome.<sup>1</sup> Mobile stroke units (MSUs)

can be used to start recombinant tissue plasminogen activator administration before hospital arrival and thereby decrease onset to treatment times in patients with acute ischemic stroke.<sup>2,3</sup> The MSU in Berlin, called Stroke Emergency Mobile (STEMO), is staffed by a neurologist with expertise in clinical neurology and trained in emergency medicine, a radiology technician, and a paramedic.<sup>4</sup> Financial, technical, and organizational requirements for the establishment and maintenance of MSUs are substantial. In the United States, vascular neurologists evaluated and recommended therapies for patients treated in an MSU via telemedicine.<sup>5</sup>

Teleneurological assessment by remote physicians can possibly reduce personnel requirements and costs.<sup>5</sup> The use of telemedicine services with the availability of a remote vascular neurologist recently showed high accuracy and reliability between onsite and remote assessment and treatment decisions.<sup>6</sup>

As previous studies had shown limitations regarding mobile telecommunication transmission or physician availability,<sup>7,8</sup> we investigated whether the audiovisual connection between STEMO and a remote destination (usually the Charité—Campus Benjamin Franklin) is technically feasible, stable,

*From the Department of Neurology, Charité—Universitätsmedizin Berlin, Campus Benjamin Franklin, Berlin, Germany (F.G., A.K., J.E.W., K.Z., H.J.A.); Department of Neurology, St. Josefs-Krankenhaus Potsdam-Sanssouci, Potsdam, Germany (B.W.); Department of Neurology, Vivantes Auguste-Viktoria-Klinikum, Berlin, Germany (M.R.); Department of Neurology, Vivantes Humboldt-Klinikum, Berlin, Germany (C.W.); Department of Neurology, Unfallkrankenhaus Berlin, Germany (M.W.); Department of Neurology, Medical Park Berlin Humboldtmühle, Berlin, Germany (A.K., M.E.); Center for Stroke Research Berlin (CSB), Charité—Universitätsmedizin Berlin, Germany (H.J.A.).*

\*Dr Geisler and Dr Kunz contributed equally to this work.

<sup>†</sup>A complete list of the Stroke Emergency Mobile (STEMO) Consortium institutions can be found in the appendix at the end of the article.

**Correspondence to:** Frederik Geisler, MD, Charité—Universitätsmedizin Berlin, Campus Benjamin Franklin, Hindenburgdamm 30, 12203 Berlin, Germany. E-mail: frederik.geisler@charite.de

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## Clinical Perspective

### What Is New?

- Teleconsultations in emergency patients with neurological deficits can be performed inside an ambulance with sufficient audiovisual quality.
- The agreement between the onboard and remote neurologist was high regarding the results of the diagnoses, the neurological examinations, and the decisions to perform systemic thrombolysis in acute stroke patients.

### What Are the Clinical Implications?

- In patients with acute neurological deficits, treated in the prehospital setting, teleconsultations offer an alternative approach to a neurologist on scene.
- One prerequisite for the technical feasibility of a teleconsultation and a high agreement of diagnosis and treatment decisions is a stable audiovisual quality, ie, the results of our study can be transferred only to areas with stable and high-bandwidth mobile connections.
- Most of the patients presented with relatively mild neurological deficits; therefore, the feasibility of examining and treating other emergency patients with potentially life-threatening conditions under the guidance of a teleconsultant was not part of our study.

and qualitatively acceptable as well as whether the assessments and treatment decisions between the onsite and remote neurologist were accurate and reliable. Therefore, we assessed audiovisual quality and the duration of teleconsultations and compared the diagnoses, scores on the National Institutes of Health Stroke Scale (NIHSS), and treatment decisions (ie, start of intravenous thrombolysis) of the onsite with the remote neurologist.

## Methods

### Study Design and STEMO Concept

All supporting data are available within the article. We analyzed patients from 2 consecutive studies: Between March 2013 and September 2013, the PrioLTE2 (Reliability of Telemedically Guided Prehospital Acute Stroke Care With Prioritized 4G Mobile Network Long-Term Evolution) study was focused on a comparison between third-generation (3G) and fourth-generation (4G) telecommunication standards regarding connectivity, audiovisual quality, and reliability of stroke assessment. Therefore, only stroke patients were included. Between October 2013 and July 2014, we conducted the TeDir (TeleDiagnostics in Prehospital Emergency Medicine [Tele-Diagnostik im Rettungsdienst]) study aiming to

assess audiovisual quality, duration of teleconsultations, and reliability of clinical decision making in the telemedicine setting. We report both studies conjunctively, as they had a major overlap of measured parameters. We included patients with acute neurological or nonneurological symptoms who were able to give informed consent and treated aboard STEMO and without need of other urgent diagnostics or treatment—either because recombinant tissue plasminogen activator -treatment had already been started or because patients had contraindications against intravenous thrombolysis, for example, being beyond the recombinant tissue plasminogen activator time window. We did not include patients with immediate life-threatening conditions that required immediate therapeutic interventions on the ambulance or transport to hospital or patients who were not able to give informed consent.

Both studies (PrioLTE2 and TeDir) were conducted in cooperation with the Deutsche Telekom (telecommunication provider, Bonn, Germany) and the telemedicine company MEYTEC (Telemedizinsysteme GmbH, Werneuchen, Germany).

The PrioLTE2 and TeDir studies were approved by the local ethics committee. Written informed consent was obtained.

STEMO is an MSU located in Berlin, Germany, equipped with a computed tomography scanner and a point-of-care laboratory and staffed by a neurologist, a radiology technician (“medizinisch-technischer Radiologieassistent”), and a paramedic (“Rettungsassistent” or “Notfallsanitäter”). After completion of a cranial computed tomography and coagulation laboratory tests as well as exclusion of contraindications, the STEMO neurologist can start prehospital intravenous thrombolysis in patients with acute ischemic stroke.

STEMO is deployed at a station of the Berlin Fire Brigade (“Berliner Feuerwehr”) in the district of Charlottenburg-Wilmersdorf. The operational area of STEMO was defined by a high probability of arriving at the scene within 16 minutes.<sup>3</sup> Details about the STEMO concept are described elsewhere.<sup>4,9</sup>

### Technical Setting and Equipment

After completion of emergency management and starting time-critical treatments, patients were asked whether they would consent to study participation. In case of patient inclusion, the STEMO neurologist informed the remote neurologist via phone, and both started the videoconference. The remote neurologist communicated with the patient using a telemedicine platform, located at the Charité—Campus Benjamin Franklin and installed in a room of the neurological walk-in clinic that is separated from the patient area and examination rooms. A notebook offered the option for the remote neurologist to communicate with the patient in cases where he or she was not at the Charité—Campus Benjamin Franklin.

We used MEYTEC GmbH (Werneuchen, Germany) telemedicine systems of Vimed car<sup>®</sup> (on STEMO) and Vimed Doc<sup>®</sup> (located in the hospital) for videoconferencing and teleradiology. Vimed car consists of a touchscreen-controlled unit in the ambulance visualizing the remote neurologist. The camera was positioned at the rear end of the patient cabin, and the microphone was fixed to the ceiling above the patient's head. The remote neurologist could move the camera in horizontal and vertical directions and zoom in and out (eg, to better examine pupils, a possible nystagmus, or eye movements) via remote control. The patient and onboard neurologist could see the remote neurologist via a flat screen at the rear end of STEMO.

Vimed Doc in the Charité—Campus Benjamin Franklin was used for remote patient consultation via videoconferencing. The H.264 standard was used for the compression of video data, and encryption was used before transmission of the data.

### Transmission of Audio and Video Data

If a 4G connection was not available at the deployment location, the system automatically switched to a 3G connection. In cases of 4G and 3G unavailability or insufficient audio or video quality, STEMO was moved to a nearby location, and the availability and audiovisual quality was reassessed. In cases of multiple connection failures or unacceptable audiovisual quality, the STEMO or remote neurologist could cancel further connection attempts and thereby abort the teleconsultation.

The German Telekom specified the maximum transmission rates for 3G connections with up to 384 Kbit/s for upload and download (with Universal Mobile Telecommunications System; up to 42.2 Mbit/s with 3G High Speed Downlink Packet Access connectivity) and for 4G connections with up to 50 Mbit/s for upload and 100 Mbit/s for download (Long-Term Evolution, LTE).

### Evaluation of Audiovisual Availability and Quality

During teleconsultation, both neurologists rated the audio and video quality separately (1=excellent [continuously accessible and excellent signal], 2=good [predominantly accessible and excellent or good signal], 3=satisfactory [predominantly accessible signal with good or at least intermediate quality], 4=sufficient [mostly accessible signal and at least intermediate quality], 5=poor [frequent loss of signal, predominantly inaccessible with intermediate or bad quality], 6=insufficient [no signal or continuously inaccessible]) and documented technical disturbances. Episodes with interruptions of the audio or video signal could be noted by the onboard and remote neurologist. When the audiovisual quality was rated "6", the teleconsultation was usually aborted because it was impossible to assess the patient.

The onsite neurologist rated the audiovisual quality of the camera depicting the remote neurologist only, whereas the remote neurologist rated the audiovisual quality of the camera depicting the patient. Thereby, both neurologists rated the quality of different cameras, and no direct comparison between the ratings was possible.

### Duration of Teleconsultations

The beginning and the end of teleconsultations and in some cases the beginning and end of the neurological examination were noted.

The duration of teleconsultation item in the PrioLTE2 cohort was completed in only 10 patients, and the PrioLTE2 checklist contained fewer items compared with the TeDir checklist, thereby leading to shorter teleconsultations. Hence, no direct comparison was conducted. Only TeDir patients were included in further analysis.

### Assessment of Onboard and Remote Diagnoses, Examination, and Treatment Decisions

We assessed interrater reliability of diagnoses, NIHSS sum scores, and treatment decisions, that is, intravenous thrombolysis, between the onboard and remote neurologist.

In the PrioLTE2 cohort, we included only patients with a diagnosis of cerebrovascular disease (transient ischemic attack, ischemic stroke, intracerebral hemorrhage). In the TeDir cohort, we also included patients with non cerebrovascular diseases or nonneurological diseases. Therefore, the agreement on diagnoses between the onboard and remote neurologist was limited to the TeDir study.

The onboard and remote neurologists were all stroke physicians with at least 3 years of experience in clinical neurology/cerebrovascular medicine and a valid NIHSS certificate.

The remote neurologist guided the patient examination by starting the assessment with collecting the medical history and asking the patient about complaints. The radiology assistant without experience in NIHSS rating but with brief training in neurological examination techniques assisted the neurological examination under guidance of the remote neurologist.

The remote neurologist was blinded to the diagnosis of the onboard neurologist and treatment decision. No communication was allowed between the onboard and remote neurologist during examination of the patient.

### Teleconsultation

At the beginning of each teleconsultation, the remote neurologist introduced her- or himself and asked questions about the chief complaints. The radiology assistant reported information on vital signs. The ECG and point-of-care

laboratory results were shown to the remote neurologist if requested by the remote physician.

Certain items were asked according to a checklist. Different checklists were used for PrioLTE2 and TeDir.

Both checklists included baseline information (name, age, and sex), beginning and end of teleconsultation, the items and sum score of the NIHSS, treatment decision (ie, intravenous thrombolysis), the recommendation of a suitable hospital for the patient (with or without a stroke unit or other hospital), and the audiovisual quality (see Table 1).

Additionally, in both studies, all inclusion and exclusion criteria for intravenous thrombolysis were asked, and it was noted whenever thrombolysis was deemed necessary for the patient (see Table 2).

On the basis of the results of the neurological examination, performed by the remote neurologist and assisted by the radiology assistant, both the onboard and remote neurologists determined the current NIHSS score.

During STEMO deployments, a remote neuroradiologist examined the computed tomography scans of the patients after transmission to his or her location and gave feedback, especially concerning possible contraindications against intravenous thrombolysis to the STEMO neurologist. Therefore, imaging assessment was not part of these studies.

The remote neurologist communicated the diagnosis, the most appropriate medical specialty the patient should be transferred to (eg, nearest hospital with a stroke unit, a neurology ward, or another center), treatment decision, and

**Table 1.** Baseline Demographics of Patients Are Depicted

	All Patients (n=90)	TeDir (n=46)	PrioLTE2 (n=44)
Age in years, mean average±SD	68.2±16.3	67.3±17.9	69.2±14.7
Female sex, n (%)	50 (55.6%)	27 (58.7%)	23 (52.3%)
MSU Audio Quality grade, mean average±SD [median, IQR] (No. of patients)	1.9±1.1 [2, 1] (72)	1.9±1.1 [2, 2] (35)	1.8±1.1 [2, 1] (37)
MSU Video Quality grade, mean average±SD [median, IQR] (No. of patients)	1.8±2.0 [1, 1] (66)	1.6±1.0 [1, 1] (37)	2.0±2.7 [1, 1] (29)
Remote Audio Quality grade, mean average±SD [median, IQR] (No. of patients)	3.1±0.9 [3, 2] (72)	3.4±0.9 [3, 1] (37)	2.8±0.8 [3, 1] (35)
Remote Video Quality grade, mean average±SD [median, IQR] (No. of patients)	2.6±0.8 [2, 1] (73)	2.8±0.9 [3, 2] (38)	2.3±0.7 [2, 1] (35)
Duration of teleconsultation in minutes, mean average±SD (No. of patients)	18.0±4.9 (56)	18.5±4.8 (46)	15.5±4.8 (10)
Agreement on diagnoses Absolute no. of patients Relative no. of patients	Cohen's $\kappa$ =0.86	40 of 43 (93.0%)	...
MSU NIHSS sum score in points, mean average±SD [median, IQR]	2.2±2.7 [1, 3]	1.9±2.8 [1, 3]	2.6±2.7 [2, 4]
Remote NIHSS sum score in points, mean average±SD [median, IQR]	2.8±3.2 [2, 4]	2.4±3.0 [1, 4]	3.1±3.4 [2, 3]
NIHSS difference in points, mean average±SD	0.9±1.3 ICC 0.87	0.8±1.3	1.0±1.3
No. of intravenous thrombolysis MSU (remote)	18 (16) Cohen's $\kappa$ =0.93	7 (5)	11 (11)

Mean average, median grades, and interquartile ranges for audiovisual quality and duration of teleconsultations in minutes are shown with the number of included patients for each item in brackets. Agreement on diagnoses, NIHSS sum score points and number of intravenous thrombolyses are depicted. Data are shown for all patients as well as for TeDir (TeleDiagnostics in Prehospital Emergency Medicine [Tele-Diagnostik im Rettungsdienst]) and PrioLTE2 (Reliability of Telemedically Guided Prehospital Acute Stroke Care With Prioritized 4G Mobile Network Long-Term Evolution) cohort separately. Different checklists were used for the TeDir and PrioLTE2 cohort (in PrioLTE2 only patients with a cerebrovascular disease were included); therefore, no direct comparison is possible between the duration of teleconsultations for both groups. For the agreement on diagnoses, NIHSS sum scores, and treatment decisions, either ICC or Cohen's  $\kappa$  is shown. ICC indicates intraclass correlation coefficient; IQR, interquartile range; MSU, mobile stroke unit; NIHSS, National Institutes of Health Stroke Scale; SD, standard deviation.

**Table 2.** All In- and Exclusion Criteria for Systemic Thrombolysis Used in the MSU

	Contraindications for Intravenous Thrombolysis	Yes	No
1.	Onset of symptoms or last-well seen >4.5 h	<input type="checkbox"/>	<input type="checkbox"/>
2.	Suspicion of Todd's paresis	<input type="checkbox"/>	<input type="checkbox"/>
3.	No relevant deficit	<input type="checkbox"/>	<input type="checkbox"/>
4.	No symptoms before begin of thrombolysis	<input type="checkbox"/>	<input type="checkbox"/>
5.	Symptoms consistent with subarachnoid hemorrhage	<input type="checkbox"/>	<input type="checkbox"/>
6.	cCT with hemorrhage or mass lesion	<input type="checkbox"/>	<input type="checkbox"/>
7.	Acute hypodense lesion in cCT, making a symptom onset within 4.5 h questionable or >1/3 of the middle cerebral artery territory	<input type="checkbox"/>	<input type="checkbox"/>
8.	Blood pressure, systolic >185 mm Hg or diastolic >110 mm Hg	<input type="checkbox"/>	<input type="checkbox"/>
9.	Bleeding (gastrointestinal or urogenital) <21 d	<input type="checkbox"/>	<input type="checkbox"/>
10.	Stroke <3 mo	<input type="checkbox"/>	<input type="checkbox"/>
11.	Intracranial hemorrhage, arteriovenous malformation, or aneurysm	<input type="checkbox"/>	<input type="checkbox"/>
12.	Head injuries <90 d or major operations <30 d	<input type="checkbox"/>	<input type="checkbox"/>
13.	Arterial puncture (not compressible)/lumbar puncture <7 d	<input type="checkbox"/>	<input type="checkbox"/>
14.	Thrombocytes <100 000/ $\mu$ L	<input type="checkbox"/>	<input type="checkbox"/>
15.	INR >1.5	<input type="checkbox"/>	<input type="checkbox"/>
16.	Blood glucose <50 or >400 mg/dL	<input type="checkbox"/>	<input type="checkbox"/>
17.	Pregnancy	<input type="checkbox"/>	<input type="checkbox"/>
18.	Neoplasms with increased likelihood of bleeding	<input type="checkbox"/>	<input type="checkbox"/>
19.	Other illness with increased likelihood of bleeding	<input type="checkbox"/>	<input type="checkbox"/>

cCT indicates cranial computed tomography; INR, internationalized normalized ratio.

additional important recommendations (eg, the application of glucose) whenever needed to the onboard neurologist.

**Statistics**

The mean average, median, and interquartile range (IQR) for most baseline parameters were computed (Table 1). Agreement on NIHSS scores between the onboard and remote neurologist was calculated with intraclass correlation coefficient using contributions of each rater individually. Values between 0.0 and 0.39 indicated a poor correlation, between 0.4 and 0.74 moderate to good, and between 0.75 and 1.0 excellent correlation. Agreement on diagnosis and treatment decisions between the onboard and remote neurologist was assessed using Cohen's kappa ( $\kappa$ ), whereas a poor agreement was interpreted between  $\kappa=0.0$  and 0.40, a

**Table 3.** Cross-Tabulation Results for the Calculation of Cohen's  $\kappa$  for Agreement on Diagnosis Between MSU and Remote Neurologist

Cross-Tabulation—Diagnosis				
Number				
Diagnosis	Remote Neurologist			Sum
	Stroke	Neurological (Except Stroke)	Other	
<b>MSU neurologist</b>				
Stroke	25	1	1	27
Neurological (Except stroke)	1	13	0	14
Other	0	0	2	2
<b>Sum</b>	<b>26</b>	<b>14</b>	<b>3</b>	<b>43</b>

MSU indicates mobile stroke unit.

moderate agreement between  $\kappa=0.41$  and 0.60, a substantial agreement between  $\kappa=0.61$  and 0.80, and an almost perfect agreement between  $\kappa=0.81$  and 0.99. The cross-tabulation results can be found in Tables 3 and 4.

For the Bland-Altman plot, the mean average NIHSS sum scores of the onsite and remote neurologists and the difference between both were computed. The mean average and standard deviation of the difference (as well as the standard error of the mean and the 95% confidence interval (CI) of the mean) were calculated for the Bland-Altman plot. The upper and lower limits of agreement were calculated with the formula: mean average of the difference  $\pm 1.96 \times$  standard deviation of the difference. Details for the generation of the Bland-Altman plot are found on IBM SPSS Support online (<https://www.ibm.com/support/home/>) and elsewhere.<sup>10,11</sup>

The statistical tests were conducted using Microsoft Excel 2016 (Microsoft Corp., Redmond, WA) and IBM SPSS Statistics 24 (IBM Corp., Armonk, NY).

**Table 4.** Cross-Tabulation Results for the Calculation of Cohen's  $\kappa$  for Treatment Decisions Between MSU and Remote Neurologist

Cross-Tabulation—Thrombolysis			
Number			
Thrombolysis Yes/No	Remote Neurologist		Sum
	Yes	No	
<b>MSU neurologist</b>			
Yes	16	2	18
No	0	72	72
<b>Sum</b>	<b>16</b>	<b>74</b>	<b>90</b>

MSU indicates mobile stroke unit.



## Results

### Inclusion and Exclusion of Patients

Overall, 90 of 103 recruited patients (PrioLTE2, 52 patients; TeDir, 51 patients) were included in our analysis. Five patients were excluded because of repeated connection difficulties and failures, making communication with the patient and thereby a teleconsultation impossible; 4 patients because of missing data; 2 because of clinical worsening; and 2 because of technical difficulties during teleconsultation, as shown in Figure 1. The mean age was  $68.2 \pm 16.3$  years (56% women), as shown in Table 1.

The variables audio and visual quality and duration of teleconsultation were incomplete for some patients. NIHSS sum scores and treatment decisions regarding intravenous thrombolysis were documented for all 90 patients. The following results are found in Table 1.

### Audio and Video Quality

The median audio quality was rated 2, IQR=1 (72 patients), median video quality 1, IQR=1 (66 patients) by the onsite neurologist and 3, IQR=2 (72 patients) as well as 2, IQR=1 (73 patients) by the remote neurologist, respectively.

### Duration of Teleconsultations

The mean average duration of a teleconsultation in the TeDir cohort was  $18.5 \pm 4.8$  min (data available for 46 patients).

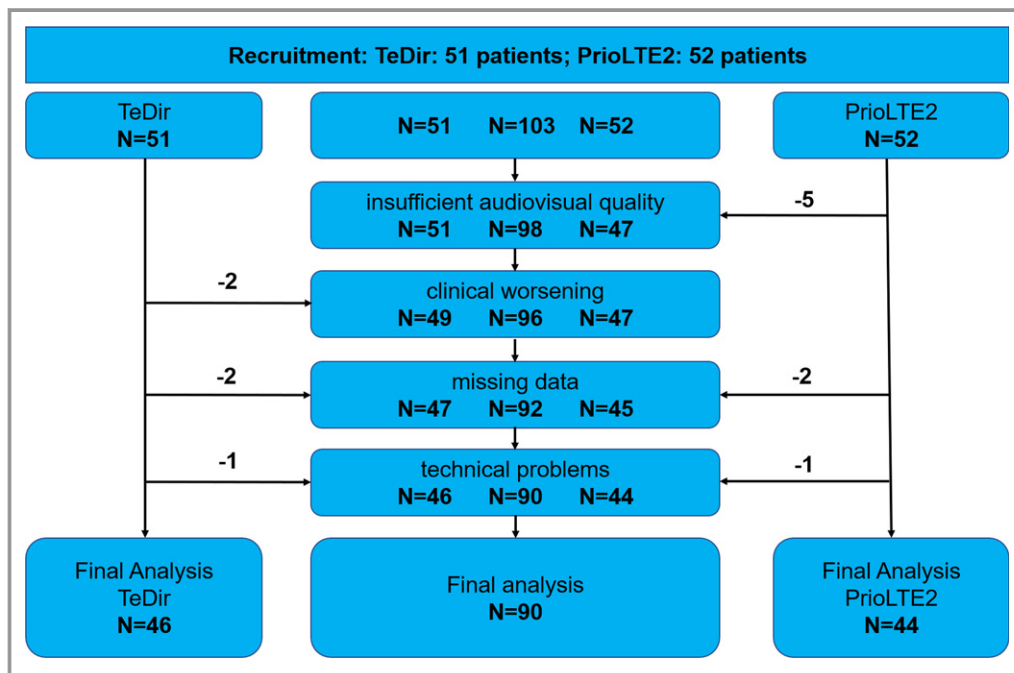
## Diagnoses of Patients

Interrater agreement regarding prehospital diagnosis was assessed in the TeDir cohort only. The onsite neurologist diagnosed acute stroke in 29 patients, neurological but noncerebrovascular disease in 14 patients, and nonneurological diseases in 3 patients. The remote neurologist felt too uncertain to make a diagnosis in 3 patients (2 stroke and one nonneurological diagnosis). In the remaining 43 patients, the onsite and remote neurologists made the same diagnosis in 40 cases and differed in 3 cases (Cohen's  $\kappa=0.86$ ), as shown in Table 3.

In 2 cases when the MSU neurologist suspected stroke as the diagnosis, the remote neurologist suspected a peripheral facial paresis and a fall in a multimorbid patient. In 1 patient, the MSU neurologist suspected a seizure and the remote neurologist a stroke.

### Agreement on Neurological Examination (NIHSS sum scores)

The median of the NIHSS sum scores rated by the MSU neurologist was 1, IQR=3 and 2, IQR=4 by the remote neurologist. In 21 of the 90 patients (23.3%), the MSU and remote neurologist disagreed by >1 point and in 10 patients (11.1%) by >2 points in the NIHSS sum score. In all 10 patients with a >2-point difference, the MSU and remote neurologist disagreed in the assessment of arm or leg paresis, and in 4 of the 10 patients facial paresis was assessed



**Figure 1.** Reasons for exclusion of patients are depicted for both studies, TeDir (TeleDiagnostics in Prehospital Emergency Medicine [Tele-Diagnostik im Rettungsdienst]) and PrioLTE2 (Reliability of Telemedically Guided Prehospital Acute Stroke Care With Prioritized 4G Mobile Network Long-Term Evolution) separately.

differently, whereas all other single items of the NIHSS were less likely to be rated differently. In 9 of these 10 patients, the NIHSS sum score was rated higher by the remote neurologist. The intraclass correlation coefficient for the agreement of the NIHSS sum score was 0.87.

### Agreement on Recombinant Tissue Plasminogen Activator Treatment

A decision for intravenous thrombolysis was made for 18 patients by the MSU neurologist, while the remote neurologist recommended thrombolytic treatment in 16 of these patients (Cohen's  $\kappa=0.93$ ), as shown in Table 4.

In one case, the symptom onset of the patient was >4.5 hours during teleconsultation but within 4.5 hours after start of treatment onboard the MSU. In the second case, the onboard neurologist decided to perform thrombolysis with an international normalized ratio of 1.6 as an individual treatment decision, and the remote neurologist decided against thrombolysis because of a contraindication to the treatment (the limit for international normalized ratio was  $\leq 1.5$  in this study).

### Discussion

Our study shows that telemedicine-enabled remote acute stroke assessment in an MSU including video examination and treatment decisions is technically feasible with acceptable audiovisual quality and a high interrater reliability between onboard and remote neurologists.

The audiovisual quality was rated high enough (audio quality 3=satisfactory and video quality 2=good) by the remote neurologist to perform a teleconsultation without significant disturbances in most cases. These findings indicate that technical advances including implementation of 4G standards in Berlin have yielded sufficient improvement for prehospital telestroke utilization—in contrast to the disappointing results of a previous study performed in Berlin based on 3G technology.<sup>7</sup> They are in line with 2 more recent studies in Brussels and Berlin that suggested feasibility and acceptable reliability of mobile telestroke assessment with remote examination of actors mimicking stroke syndromes.<sup>12,20</sup> After implementation of the first MSU in the United States in Houston, Texas,<sup>6,13–16</sup> this group and a group from Cleveland, Ohio, showed that telemedicine in patients with stroke is feasible, reliable, and accurate, with decreased time to imaging and treatment.<sup>5,17</sup>

The quality of both modalities (audio and visual) was rated better by the MSU neurologist compared with the remote neurologist. However, the onboard neurologist rated the quality of the connection to the remote neurologist and thereby only audiovisual connection to the hospital, whereas

the remote neurologist rated the quality of the connection to the MSU (including the assessment and examination of the patient). The onboard and remote neurologist rated the qualities of pictures from 2 different cameras, making direct comparisons of the quality ratings difficult and can explain the difference in the assessment.

The time to complete the medical history, examination, and treatment decision was about  $18\pm 5$  minutes for both studies, although the TeDir checklist was comprehensive, suggesting that shorter documentation forms, designed for specific syndromes, for example, may result in shorter treatment decision times.

The interrater reliability of diagnoses between the MSU and onboard neurologist was high in the TeDir cohort and differed in only 3 of 43 patients (7.0%; Cohen's  $\kappa=0.86$ ), indicating an overall high agreement. Possibly, missing information of witnesses or relatives (available only for the MSU neurologist) played an important role in the different assessments, which represents the most critical argument against telestroke assessment in this highly time-critical setting.

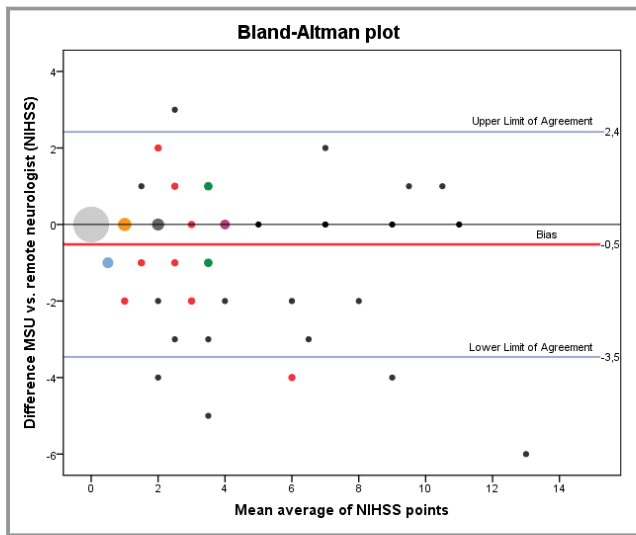
The interrater reliability of the NIHSS sum scores between the MSU and remote neurologist was high (intraclass correlation coefficient, 0.87) and is in line with a previous study that showed a high intrarater and interrater reliability of a novel score and the NIHSS between an on-scene and remote neurologist.<sup>8</sup> Another group confirmed a high agreement of 88% (Cohen's  $\kappa=0.73$ ) of all evaluations between the onboard and remote neurologist.<sup>6</sup> In some patients, the NIHSS rating of the onboard neurologist was different by  $\geq 2$  points compared with the remote neurologist. Possibly, technical disturbances (eg, poor audio or video quality during assessment) impaired the validity of the measurement (Figure 2).

Other telemedicine-based MSUs showed shorter median alarm-to-imaging and alarm-to-thrombolysis times<sup>17</sup> as well as shorter median door-to-thrombolysis times (32.0 and 31.5 min.) compared with regular care.<sup>5,17</sup>

These findings are in line with our group showing shorter alarm-to-needle times<sup>2</sup> and a trend toward a better functional outcome in patients treated by neurologists aboard an MSU<sup>3</sup> and other authors reporting the feasibility of telemedicine with a varying but overall high reliability between onsite and remote diagnoses.<sup>8,18,19</sup>

In 2 of 18 patients, the remote neurologist did not recommend intravenous thrombolysis, although the patient received this treatment onboard the MSU, but these deviations were explained by different time windows (the patient was within the 4.5-h time window when MSU treatment was initiated and beyond the time window when the teleconsultation was conducted) and 1 individual treatment decision (thrombolysis of a patient with an international normalized ratio of 1.6).

Certain limitations must be considered.



**Figure 2.** Bland-Altman plot for the agreement of the neurological examination between the mobile stroke unit (MSU) and remote neurologist as measured in National Institutes of Health Stroke Scale (NIHSS) points. Mean average of the difference between both neurologists is  $-0.52$  (mean average of difference  $= -0.52$ ; 95% CI,  $0.84-0.21$ ), shown as the red horizontal line, the upper and lower limits of agreement are  $2.42$  and  $-3.46$  (blue horizontal lines). The difference in NIHSS points is depicted on the y axis and the mean average of NIHSS points on the x axis. Some scores were shared by  $>1$  patient. The more simultaneously shared scores, the larger the diameter of the circles; that is, light gray=26 patients, orange=7 patients, gray=6 patients, light blue=5 patients, cyan=4 patients, green=3 patients, red=2 patients.

First, 12.6% of the teleconsultations were not completed because of technical difficulties (including failure of video connection) or clinical worsening. The rate of aborted attempts was therefore higher than in previous studies—1% in Cleveland and 2% in Houston.<sup>5,6</sup> Our result represents a relevant proportion of remotely examined patients who required onboard medical examination.

Second, the number of patients is relatively small. However, in accordance with previous studies, agreement on diagnosis and treatment decisions seems to be satisfactory.

Third, the patients had on average a low NIHSS sum score, thereby reflecting a cohort of stroke patients with relatively mild deficits able to give written informed consent.

Fourth, we included data of 2 separate studies with different assessment checklists, making some items, especially hospital destination, impossible or difficult to compare.

However, for all included patients, the NIHSS sum score as well as treatment decisions were documented.

## Summary

In conclusion, this study suggests that acute stroke assessment and clinical decision making in patients onboard an MSU can be reliably performed by a remote neurologist. Technical

failures still represent a relevant limitation of the prehospital telemedicine-based approach.

## Appendix

### STEMO Consortium

Berliner Feuerwehr, Berlin, Germany; Charité—Universitätsmedizin Berlin, Berlin, Germany; MEYTEC, Werneuchen, Germany.

### Disclosures

Dr Audebert received speaker honoraria from Boehringer Ingelheim (manufacturer of alteplase; not involved in any form in the trial) and Siemens as well as speaker honoraria and honoraria for consultancy from Lundbeck Pharma (sponsor of trials with desmoteplase in stroke). The remaining authors have no disclosures to report.

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